U.S. Environmental Protection Agency

Office of Air and Radiation

Office of Mobile Sources

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FINAL REPORT

Contract 68-C2-0125

Work Assignment 1-1

Study of In-Use Air-Conditioner Operation in Phoenix, Arizona

The Clean Air Act Amendments of 1990 (CAAA) require modifications to the Federal Test Procedure (FTP) to make it more representative of "real world" conditions. The operation of a vehicle's air conditioning system can have significant impact on emissions, especially oxides of nitrogen (NOx). Current FTP methodology for simulating air conditioner operation (adding 10% to the road load horsepower) clearly under represents the load of the air conditioner and the resultant emissions impact. The purpose of this Work Assignment was to collect in-use data to characterize how vehicle air conditioners are used by the public. Specifically, the EPA was interested in how drivers operate the air conditioning equipment in their vehicles, and how the A/C compressor behaves when the A/C is activated.

Two separate testing phases were originally planned for the Work Assignment. The first testing phase required the instrumentation of fifteen in-use vehicles with EPA-supplied data acquisition equipment. Monitored parameters were to include A/C switch on/off status, A/C clutch energized/deenergized status, and vehicle speed. Vehicles were to be driven by their owners during their normal daily routines for a two week period. The second phase of testing was to be performed on a proving ground. This phase of the work assignment specified the instrumentation of five vehicles, recording A/C clutch on/off, A/C compressor head pressure, condenser temperature, vehicle speed, RPM, and coolant temperature while being operated on the test track over specified driving cycles.

The phase two testing was originally included as a contingency if similar testing then being planned by the manufacturer was not in fact completed. It became clear that the vehicle manufacturers would complete their testing program, permitting EPA to redirect its testing resources to additional phase 1 test vehicles. The five vehicles originally specified for phase two testing were added to the phase one fleet. A total of 20 vehicles, therefore, had the EPA-supplied data acquisition systems installed and were used to characterize air conditioner operation during normal road operation by the vehicle owners.

Vehicle Selection and Recruitment

Passenger cars and light duty trucks (LDT1) were eligible to participate in this program. All vehicles in this study were equipped with an R-134A air conditioning system. A representative mix of vehicle types and manufacturers was required.

Three methods were used to identify candidate vehicles. The first method of selection was performed at an enhanced I/M lane operated by ATL employees in Mesa, Arizona under other Work Assignments for EPA. Vehicles that received a State I/M test were also inspected for the presence of an R-134A air conditioning system. Owners of eligible vehicles were approached, and were asked to participate in the program. Four vehicles were procured at the lane. The second method of procurement included referrals from local automotive dealerships and independent repair facilities. Twelve customers from the local facilities agreed to participate in this Work Assignment. The third method used referrals from friends and relatives of ATL employees. Four vehicles were procured with this method.

A non-intrusive incoming inspection was performed on each vehicle Detailed vehicle identification data was recorded, including vehicle make, model, year, engine displacement, induction system, VIN, engine family, and evap family. A visual underhood inspection was performed to detect gross tampering and other non-representative conditions. Table 1 lists the vehicles that were selected to participate in this program.

Incentives for participation in this program were:

- A check for $50 was issued to the vehicle owner when the vehicle was delivered to the lab and the data acquisition system was installed.
- A check for $50 was issued to the vehicle owner when the vehicle returned to the lab to remove the data acquisition system.

Datalogger Installation and Calibration

Ten data loggers manufactured by Instrumental Solutions were supplied to ATL by EPA. Nine of the ten data loggers were powered up, and dates and time were programmed into the acquisition systems. The tenth data logger was inoperative and was returned to the Work Assignment Manager. It was repaired, returned to ATL, and used later into the program.

Data parameters collected on the twenty vehicles on a trip basis included:

- A/C switch on/off (proportion of trip time and seconds in each position)
- A/C clutch on/off (proportion of trip time in "on" position)
- MPH (percent distribution in 5 mph "bins")

- Time (trip start, trip duration)
- Date (trip start)

Several problems were encountered during equipment installation. The data loggers were programmed to consider battery voltage levels as a signal that the A/C switch and A/C clutch was on, and to interpret zero voltage as switch or clutch off. Ten of the twenty vehicles used the opposite logic, and displayed zero volts when the switch or clutch was on, and battery voltage when the system was off. Voltage inverters were assembled by ATL to reverse the voltage readings sensed by the data loggers to obtain compatible information with the data logger program.

A buffer device was required for proper operation with three of the selected vehicles. It appeared as if the data logger drew too much current, causing the A/C system to operate improperly when a data logger was installed. Once the buffer was installed, the A/C systems worked as designed.

Three vehicles could not be successfully instrumented, even with the buffers and inverters. These vehicles were released back to the owners, and were not included in this program. Three other vehicles were recruited to replace them.

After the equipment installation had been completed, calibrations were required to record correct vehicle speed readings. There were three steps to this procedure. The calibration "modes" were accessed when a lap top computer was connected to the acquisition system. During the first step, the vehicle was driven exactly one mile while the acquisition system was in the "calibration" mode. The data logger computed a conversion factor (pulse per mile) during this step.

The second step ensured that the first step was completed correctly. The vehicle was driven with the acquisition system in the "road test" mode. Continuous speed readings were displayed on the lap top computer in this mode. The vehicle was driven at several different speeds while monitoring both the vehicle speedometer and the lap top computer. The data logger was considered calibrated correctly when the two speed readings agreed to within two miles per hour. The A/C clutch and A/C switch were also monitored in the road test mode. The A/C switch was turned on and off several times to ensure that the correct data was being captured.

The third step was to confirm that the data logger could record and display a driving cycle or "trip". The "record" mode was entered on the lap top computer, then the engine was started. The vehicle was driven for approximately five minutes. The vehicle was stopped, and the engine shut off. The data logger was accessed to ensure that reasonable information had been recorded. These procedures were performed after equipment installation on each vehicle.

Field Problems

Four vehicles were equipped with a data logging system the first week (vehicle # 501-504). Once the acquisition systems were installed and calibrated, the owners were instructed to drive their vehicles as they normally would for two weeks. At the end of the two week period, the owners were requested to return to the laboratory to remove the data logging system. The first acquisition system (vehicle #501) was installed in a vehicle owned by an ATL employee. For the first week, the data from this system was retrieved and checked daily for any system malfunctions.

The system was thought to be functioning correctly, and the remaining data loggers were installed, and the equipped vehicles returned to the owners. Data was not accessed on vehicles #502 through #504 until the end of the second week. The acquisition systems were accessed by lap top computer to download the information, and several days of data was missing. Data from vehicle #503 had been captured for the first day only, and there were four days of data captured on vehicle #502. By the time this problem was discovered, data acquisition systems had been installed on vehicles #505 through #511.

The acquisition system had been installed in vehicle #505 for one week. The owner was contacted, and requested to return his vehicle to the laboratory. The data system was accessed, and no data was recorded. The system was recalibrated, and two trips were recorded. After the trips, the vehicle was brought back to the lab in order to retrieve the data. Both trips had been recorded by the data logger.

The acquisition system was removed from vehicle #505. The cover was removed from the data logger, and the acquisition system was manually connected to a lab power supply and powered up. A lap top computer was connected to the data logger, and the data from the two previous road trips was displayed. A slight pressure was exerted on the prom board, and all information on the lap top computer display was lost. A preliminary visual inspection of the acquisition systems at the laboratory indicated there was a loose prom board to circuit board connection.

Instrumental Solutions was contacted for assistance, and made aware of our problem. At this time, ATL was informed that there was an updated prom to be released, but the prom change did not relate to the problem that was experienced with the data loggers in Phoenix. It was suggested by Instrumental Solutions that extreme inside vehicle heat may also be responsible for the lost data. In order to duplicate this problem and to discover the root cause of the problem, inside vehicle temperatures of 158° F and road vibration were simulated on several data loggers at Instrumental Solutions.

A Rustrack data logger was installed in vehicle #508 to monitor and record inside vehicle temperature. A "J" type thermocouple was installed next to the acquisition system. These temperatures were measured continuously from September 9, through September 14, 1995. The temperatures varied from 70° F to 125° F. The temperatures did not go above 158° F.

The updated proms were received from Instrumental Solutions and were installed, but the loose connection was still present. The prom boards were double taped and rubber support "feet" were installed as an ATL "field fix", to prevent intermittent circuit board connection losses due to vehicle road vibration. The problem was duplicated at Instrumental Solutions, and incorrect thickness of the prom board was determined to be the root cause of the problem. For the rest of the work assignment, the field fix with the rubber feet and double tape was used. Owners were now requested to return at the end of the each week to examine the data acquisition system, and download all stored information.

The owner of vehicle #503 had only two trips on the first day recorded. This person went camping, left his lights on, and the vehicle battery went dead. When the vehicle battery is disconnected or goes dead, the data logger has to be reprogrammed and recalibrated to record data properly. He returned to ATL, and this one trip was downloaded. A new date and time was entered back into the data logger, the speedometer reading to the data logger was recalibrated, and a trip was recorded prior to giving the vehicle back to the owner. The vehicle returned after the second week of operation, and there were no trips stored in the acquisition system.

Data loggers installed in vehicles #502-#504 were not accessed until the end of the second week. Five vehicles (#505, #507, #508, #509, and #514) had no data recorded during the first week. All data captured was during the second week of operation on these vehicles. Vehicle #506 was at the end of the two week driving cycle. There were no trips recorded in a two week period. The owner of vehicle #506 was asked to again participate for another two weeks. The same incentives were applied. The prom field fix was performed, and the acquisition system now recorded fifty four trips in twelve days of operation.

No data was captured on vehicle #510 during the first week of operation. The acquisition system was updated, and checked again at the end of the second week. There was no data recorded for the second week. The acquisition system was removed from this vehicle, and installed in another vehicle. Prior to calibrating the speed sensor signal, the data logger lost all communications with the lap top computer. There were similar occurrences with the acquisition systems in vehicles #513 and #519. The root cause of this problem was not found, and these acquisition systems were not used again in this program. During the first week of operation, the owner of vehicle #515 did not drive the vehicle for three days. Information was recorded on September 15, and then again on September 19, 1994.

Results

The primary objective of this Work Assignment was to collect data to define the operating characteristics of vehicle air conditioner systems during normal road use. Twenty vehicles were ultimately

equipped with the data acquisition systems. Data was collected once a week from these twenty vehicles, and copied to a floppy disk, and forwarded to the Work Assignment Manager.

A total of 1005 trips and 132 days of information were recorded from the 20 vehicles selected for this program. Table 2 lists the numbers of trips and days that the information was recorded for each vehicle.

Table 1

Veh#	Year	Make	Model	Engine Fam	Evap Fam	VIN	CID	Fuel
501	94	Dodge	Shadow	RCR2.5V5GAEA	RCR1050AYM03	1B3AP28K7RN182914	2.5L	TBI
502	93	Jeep	Cherokee	PCR5.9T5FEY4	PTAPH	1J4GZ88Y7PC679717	5.2L	PFI
503	94	Dodge	Ram	RCR5.988GAEA	RCR1065AYPUA	1B7HC16Z2RS624183	5.9L	PFI
504	94	Ford	Taurus	RFM3.0V8GFEA	RFM1045AYM0A	1FALP52U9RG142802	3.0L	PFI
505	94	Nissan	Sentra	RNS1.6VJGFEA	RNS1030BYM0A	1N4GB31F5RC703406	1.6L	PFI
506	94	Toyota	Camry	RTY3.0VJFEK	RTY1073DYM00	JT2GK12E8R0061142	3.0L	PFI
507	94	Dodge	Caravan	RCR3.328GDEA	RCR1095AYM0A	1B4GH54R9RX278488	3.3L	PFI
508	94	Toyota	Paseo	RTY1.5VHGAFB	RTY10470YM00	JT2EL45UXR0180464	1.5L	PFI
509	94	Chrysler(conv)	Lebaron	RCR3.0V8GBEA	RCR1050AYM02	1C3EU453XRF315584	3.0L	PFI
510	94	Nissan	Pick up	RNS2.47JGAEA	RNS1030BYM0B	1N6SD11S4RC315153	2.4L	PFI
511	94	Nissan	Pick up	RNS3.078GAEA	RNS1057BYM0C	1N6HD16S7RC377701	3.0L	PFI
512	94	Chevrolet	Suburban	R3G5.785GAEB	R3G1085AYM0A	1GNEC16K5RJ378714	5.7L	TBI
513	95	Ford(conv)	Mustang	SFM5.0V8GAJA	SFM1045AYM0A	1FALP45T9SF114877	5.0L	PFI
514	94	Nissan	Pick up	PNS2.4T5FAF7	F14-4	1N6SD16S3PC420871	2.4L	PFI
515	94	Ford	Aerostar	RFM3.088GAEA	RFM1045AYP0A	1FMDA31U2RZB53761	3.0L	PFI
516	94	Chevrolet	Astro Van	R3G4.385GAEB	R3G1085AYM0N	1GNDM19Z1RB240969	4.3L	TBI
517	94	Ford	Taurus	RFM3.8V8GAEA	RFM1045AYC0A	1FALP5240RG104097	3.8L	PFI
518	94	Nissan	Sentra	RNS1.6VJGFEA	RNS1030BYM0A	1N4EB31P0RC752120	1.6L	PFI
519	94	Volvo	240	PVV2.3V5F88X	E2	YV1AS8805P1487311	2.3L	PFI
520	94	Geo	Metro	RSK1.0VGDFA	RSK1030BYM01	2C1MR6466R6779941	1.0L	TBI

Table 2

Veh #	Year	Make	Model	Trips Recorded	Days Recorded	Days in Program
501	94	Dodge	Shadow	109	13	14
502	93	Jeep	Cherokee	43	4	14
503	94	Dodge	Ram	2	1	14
504	94	Ford	Taurus	82	8	14
505	94	Nissan	Sentra	16	3	14
506	94	Toyota	Camry	54	12	28
507	94	Dodge	Caravan	21	4	14
508	94	Toyota	Paseo	35	6	14
509	94	Chrysler	Lebaron	16	3	14
510	94	Nissan	Pick up	0	0	14
511	94	Nissan	Pick up	82	15	15
512	94	Chevrolet	Suburban	110	12	14
513	95	Ford	Mustang	57	4	14
514	94	Nissan	Pick up	58	7	14
515	94	Ford	Aerostar	13	3	14
516	94	Chevrolet	Astro Van	79	9	14
517	94	Ford	Taurus	34	7	14
518	94	Nissan	Sentra	68	10	14
519	94	Volvo	240	39	3	14
520	94	Geo	Metro	87	8	14